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This project investigated the source of priority pollutants, assessment of the wastewater treatment plant, and priority pollutant removal efficiency for a single Soderberg-type primary aluminum plant. Forty-eight hour composite samples were collected from the following streams: 1) plant intake water; 2) wastewater from the primary air pollution control system (gas stream cooling water and wet EPS's); 3) secondary air pollution control system (room ventilation wet scrubber liquor); 4) paste plant briquette cooling water; and 5) final effluent after the wastewater treatment plant.

Wastewater from the primary air pollution control system entered a conventional chemical coagulation (using slacked lime)-clarification plant. Clarified water from the clarifier was combined with the other three wastewater streams and flowed into a settling lagoon with a 20-hr hydraulic retention time. Clarified lagoon water was finally discharged to the river. The principal source of organic compounds in the wastewater was from the primary and secondary air pollution control systems and results from the volatilization of petroleum coke and pitch in the Soderberg anode. Wastewater treatment plant removal efficiences of greater than 85% were achieved for the majority of the organic priority pollutant species detected.

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April 1979

ANALYSIS OF PRIORITY POLLUTANTS AT A PRIMARY ALUMINUM PRODUCTION FACILITY

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FOREWORD

When energy and material resources are extracted, processed, converted, and used, the related pollutional impacts on our environment and even on our health often require that new and increasingly more efficient pollution control methods be used. The Industrial Environmental Research Laboratory - Cincinnati (IERL-Ci) assists in developing and demonstrating new and improved methodologies that will meet these needs both efficiently and economically.

This report evaluates the removal efficiency of the 129 priority pollutants due to existing wastewater treatment technology at a single Soderberg-type primary aluminum plant. A brief process description and a detailed description of sampling, analytical, quality assurance, and treatment plant assessment are presented. Results of the investigation will enable EPA to identify which priority pollutants are being emitted by industry and to determine the ability of wastewater treatment technologies to remove priority pollutants. Questions or comments regarding this report should be addressed to the Metals and Inorganic Chemical Branch of the Industrial Environmental Research Laboratory in Cincinnati.

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Director
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ABSTRACT

As a result of the 1976 consent decree resulting from the National Resources Defense Council et al., v Train suit, EPA is obligated to identify which of the 129 priority pollutants are present in industrial wastewaters and to determine the ability of various wastewater treatment technologies to remove these priority pollutants. This project investigated the source of priority pollutants, assessment of the wastewater treatment plant, and priority pollutant removal efficiency for a single Soderberg-type primary aluminum plant.

Forty-eight hour composite samples were collected from the following streams: 1) plant intake water; 2) wastewater from the primary air pollution control system (gas stream cooling water and wet EPS's); 3) secondary air pollution control system (room ventilation wet scrubber liquor); 4) paste plant briquette cooling water; and 5) final effluent after the wastewater treatment plant.

Wastewater from the primary air pollution control system entered a conventional chemical coagulation (using slaked lime)-clarification plant. Clarified water from the clarifier was combined with the other three wastewater streams and flowed into a settling lagoon with a 20-hr hydraulic retention time. Clarified lagoon water was finally discharged to the river.

The principal source of organic compounds in the wastewater was from the primary and secondary air pollution control systems and results from the volatilization of petroleum coke and pitch in the Soderberg anode. Wastewater treatment plant removal efficiencies of greater than 85% were achieved for the majority of the organic priority pollutant species detected.

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SECTION 1

INTRODUCTION

On 7 June 1976 the U.S. District Court of Washington, D.C., issued a consent decree (resulting from Natural Resources Defense Council et al., v Train) requiring EPA to enhance development of effluent standards for 21 industrial point sources, including nonferrous metals manufacturing. Among other requirements, the court mandate focused federal water pollution control efforts on potentially toxic and hazardous chemical compounds. As a result, a list of 129 surrogate chemicals, known as priority pollutants, was established. The consent decree obligates EPA to identify which priority pollutants are present in industrial wastewaters and to determine the ability of various wastewater treatment technologies to remove priority pollutants.

Therefore, the objective of this project was to provide accurate data on the concentration of the 129 priority pollutants in wastewater samples collected from a single primary aluminum plant equipped with a well designed wastewater treatment plant. In addition, the removal efficiency for priority pollutants was evaluated.

This report provides a brief process description and a detailed description of the sampling, analytical, and quality assurance procedures employed. Analytical results and evaluation of the treatment plant are then presented.

SECTION 2

SUMMARY

The purpose of this project was to provide accurate data on the concentration of the 129 priority pollutants in intake water and wastewater samples collected from a single primary aluminum plant equipped with an examplary wastewater treatment plant. Data were then used to evaluate treatment plant removal efficiencies for priority pollutants.

Fortyeight hour composite samples were collected from the following streams: (1) plant intake water; (2) wastewater from primary air pollution control system (gas stream cooling water and wet ESP's); (3) secondary air pollution control system (room ventilation wet scrubber liquor); (4) paste plant briquette cooling water; and (5) final effluent. The sample collection technique followed that recommended by EPA for priority pollutant analysis, with a few modifications designed to better insure sample integrity, chain of custody, and to address site specific requirements. Because of the way the wastewater treatment plant was constructed, a grab sampling technique was used instead of using automatic samplers. A sample was collected from each stream every hour for 48-hr using a Teflon -lined, 3-gal stainless steel bucket. Aliquots were removed from the bucket with glass beakers and placed in appropriate sample containers. By maintaining the proper preservatives, this technique allowed field composite samples for total cyanide and total phenol instead of a single grab sample as EPA recommended. Sample containers were labeled, sealed, packed in ice, and airfreighted to MRC for analysis.

The priority pollutant analysis scheme divides the compounds into eight fractions for analysis: volatile organics, base/neutral organics, acid organics, pesticides and PCB's, metals, cyanide (total), phenol (total), and asbestos.

It is important to realize that some of the organic priority pollutant analysis procedures are still under development and require further verification and validation. Therefore the data presented for organic species serve to identify which of the 129 pollutants were present and to indicate the general concentration ranges within a factor of two.

Two chemical species were not analyzed in this project: 2,3,7,8-tetrachlorodibenzo-*p*-dioxin (TCDD) as recommended by EPA because of the hazard involved in preparing laboratory standard solutions; and asbestos. However, samples for potential future asbestos analysis were collected, preserved, and stored at 4°C. Since there are no sources of pesticides in aluminum production, the pesticide analysis fraction was also elimirated.

A summary of the analytical results is presented in Table 1. Only those organic compounds detected in the samples are presented in the table. Values in Table 1 are reported in mass flow rate units (g/day) to eliminate apparent dilution effects when reporting values in stream concentration units. Mass flow rate was determined by multiplying species concentration by the appropriate stream flow rate.

From the mass flow rate data, the removal efficiency for priority pollutants by the wastewater treatment plant were calculated. This value was calculated by subtracting the sum of the values in columns two through four from the value in column five and dividing the difference by the sum of columns two through four.

The wastewater treatment plant was a conventional chemical coagulation-clarification plant. Slaked lime (CaO) was added to the wastewater stream from the primary air pollution control system. This stream then went to a 1.09×10^6 ℓ clarifier with a hydraulic retention time of two hours. Sludge was sent to sludge holding lagoons which had no resulting wastewater discharged. Clarified water from the clarifier was combined with the other wastewater streams and flowed to a settling lagoon with a 20-hr hydraulic retention time. Clarified water from the lagoon was finally discharged to the river.

The principal source of organic compounds in the wastewater was from the volatilization of petroleum coke and pitch in the Soderberg anode. These oil and tar vapors were subsequently collected in the primary and secondary air pollution control equipment. Wastewater resulting from gas stream cooling, wet ESP's, and wet scrubber liquor was discharged to the treatment plant.

Based on the values in Table 1, removal efficiencies of greater than 85% were achieved for the majority of the organic priority pollutant species detected. Organic species with lower removal efficiencies included bis(2-ethyl hexyl)phthalate, acenaphthene, pyrene, fluoranthene, and total phenol.

TABLE 1. TREATMENT PLANT REMOVAL EFFICIENCIES FOR PRIORITY POLLUTANTS

Primary pollutant	Mass flow rate in stream, g/day					Percent removal[a]
	Intake water	Primary control system	Secondary control system	Paste plant discharge	Final effluent	
Bis(2-ethyl hexyl) phthalate	1,470	65	1,560	30	670	32
Naphthalene	-[b]	260	-	-	-	100
Acenaphthene	-	650	40	3	670	3
Acenaphthylene	-	50	-	-	470	-[c]
Fluorene	-	650	-	3	70	89
Phenanthrene	-	230	-	15	-	100
Anthracene	30	1,960	520	15	200	91
Pyrene	70	2,870	2,590	70	2,660	52
Fluoranthene	70	4,170	5,700	80	5,330	46
Chrysene	-	3,000	1,560	80	600	87
Benzo(a)anthracene	150	2,350	2,070	80	530	88
Benzo(b)fluoranthene	-	3,390	-	-	-	100
Benzo(k)Fluoranthene	220	2,740	-	110	470	84
Benzo(a)pyrene	150	7,440	2,070	100	670	93
Dibenzo(a,h)anthracene	-	1,430	-	-	-	100
Indeno(1,2,3-cd)pyrene	-	4,570	100	20	70	99
Benzo(1,2,3-cd)perylene	-	1,960	100	20	70	97
Phenol	-	910	-	-	-	100
Methylene chloride	150	100	-	10	-	100
Toluene	150	40	-	5	-	100
Benzene	-	80	-	-	-	100
Phenol (total)	290	3,590	8,190	170	7,730	37
Antimony (total)	2,200	5,800	2,600	50	2,700	68
Copper (total)	400 ± 50	400	1,100	14 ± 1	600 ± 90	60 ± 3
Nickel (total)	590 ± 100	14,700 ± 1,100	<260	<8	330	98 ± 2
Zinc (total)	2,100 ± 150	1,500	2,400	60	2,300 ± 130	42 ± 2

[a]Value calculated by subtracting the sum of columns 2 through 4 from the value in column 5 and dividing the difference by the sum of columns 2 through 4 and converting into percent.

[b]Blanks indicate species not present in stream sample.

[c]Nondeterminable--value in effluent greater than sum of input values.

Of the thirteen priority pollutant metals only four were detected above instrument detection limits: antimony, copper, nickel, and zinc. Removal efficiency data indicated the treatment plant was very effective at removing nickel and moderately effective at removing antimony, copper, and zinc.

SECTION 3

SOURCE DESCRIPTION

PROCESS DESCRIPTION

Large scale, economic production of primary aluminum became possible when, in 1886, Charles Martin Hall and Paul Heroult independently invented the electrolytic process. The Hall-Heroult process has remained essentially unchanged since its inception, except for equipment design modifications and improvements in operating practice, and is employed in all commercial United States production of primary aluminum (1).

In general, the process involves passing a continuous current through an electrolytic cell containing alumina (Al_2O_3) dissolved in molten cryolite ($AlF_3 \cdot 3NaF$) which is maintained at 940°C to 980°C (2). As electrolysis proceeds, aluminum settles to the bottom of the cell at the cathode and is periodically tapped and drained.

Oxygen is evolved at the carbon anode at the top of the cell and reacts with the carbon to produce a mixture of carbon monoxide (CO) and carbon dioxide (CO_2), thus consuming the carbon anode.

Primary aluminum plants in the United States are classified by the method used to replace carbon anodes. The two methods are referred to as the prebaked anode (intermittent replacement) and the Soderberg anode (continuous replacement). The plant sampled in this study used the Soderberg anode type cells with vertical anode studs for carrying current (Figure 1). This type of plant is referred to as a vertical stud Soderberg design.

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(1) Thompson, G. S., Jr. Development Document for Effluent Limitations Guidelines and New Source Performance Standards for the Primary Aluminum Smelting Subcategory of the Aluminum Segment of the Nonferrous Metals Manufacturing, Point Source Category. EPA-440/1-74-019d (PB 240 859), U.S. Environmental Protection Agency, Washington, D. C., March 1974. 142 pp.

(2) Kirk-Othmer Encyclopedia of Chemical Technology, Volume I. John Wiley and Sons, Inc., New York, New York, 1963. pp. 931-944.

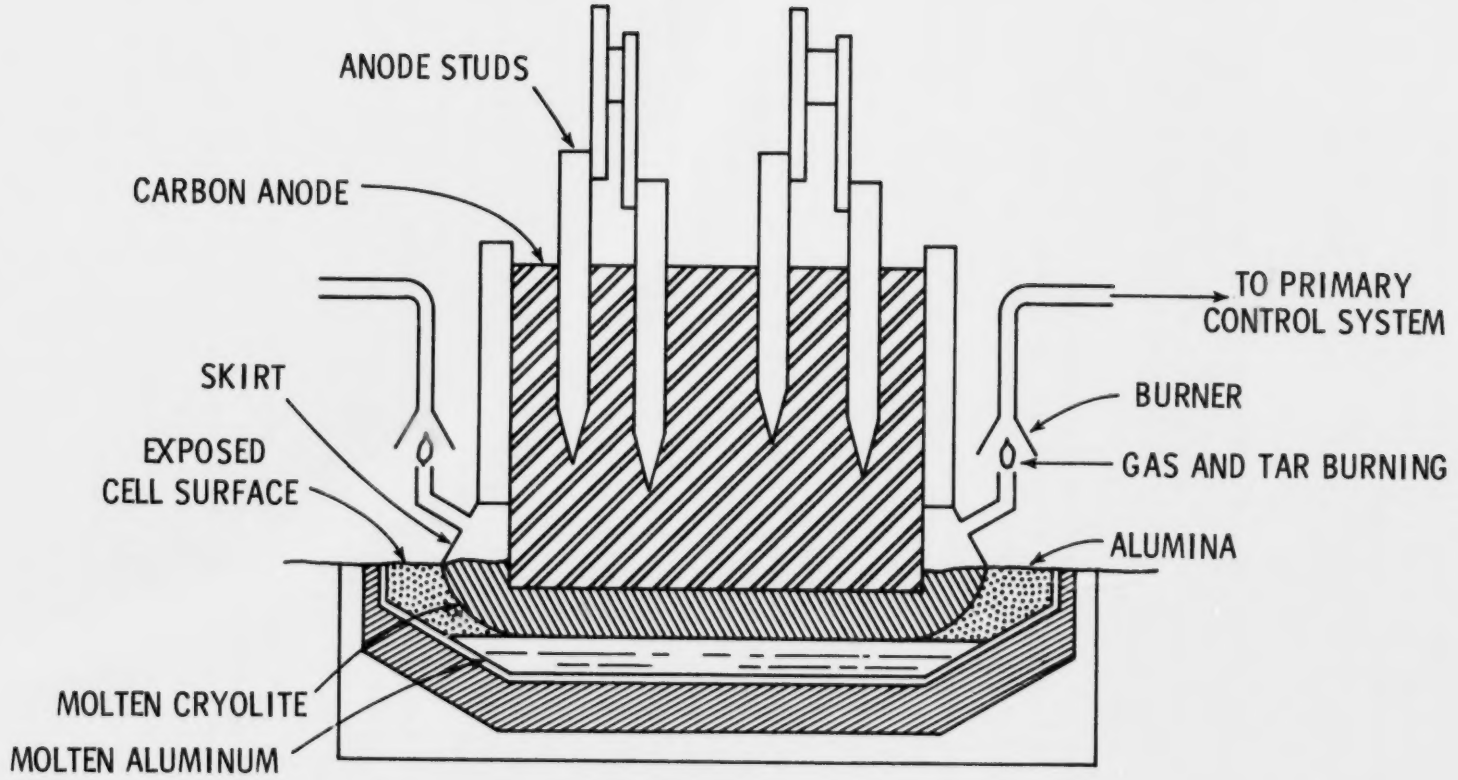

Figure 1. Schematic drawing of a vertical stud Soderberg aluminum reduction cell (1).

For the plant sampled, anode preparation began in the anode paste plant, where petroleum coke and solid pitch were hot blended. The anode paste was then formed into briquettes. Hot briquettes are then dropped into a trough of water for cooling. Briquette cooling water was discharged to the wastewater treatment plant at a flow rate of 13 ℓ/s to 19 ℓ/s (200 to 300 gpm) and neutral pH.

For the Soderberg anode design, briquettes were fed batchwise into the top of the carbon anode. As the briquettes settled and approached the hot bath, the paste was baked in place to form the anode. Tars and oils characteristic of anode baking were evolved as a fume at the cell.

The plant sampled contained 300 electrolytic cells, or pots, electrically connected in series to form two potlines arranged in two and one-half potrooms, with two potlines per room.

Continuous evolution of gaseous reaction products from each aluminum-reduction pot results in a large volume of fume which consists of CO, CO_2, volatile fluoride compounds, fine dust consisting of cryolite, aluminum fluoride, alumina, and carbonaceous material and organic compounds from the coke and pitch used to make anode briquettes. These air emissions were controlled, as shown in Figure 1, by installing a skirt around the edge of the anode, at the interface between molten electrolyte and Soderberg anode, Figure 2. A gas burner was designed in the vent line to burn organic vapors before venting to the primary air pollution control device. Spray chambers were installed between the fan and control device to lower the gas temperature (90°C to 150°C) to 27°C to 38°C.

The air flow rate from each pot was 0.19 to 0.24 standard m^3/s (400 to 500 scfm). At the plant sampled, wetted-wall electrostatic precipitators (ESP) were used to control primary air emissions. Eight ESP's, each controlling emissions from 30 pots, and four ESP's each controlling 15 pots were used. Each of the eight larger ESP's had an air flow rate of 5.7 standard m^3/s (12,000 scfm) and each of the four smaller ESP's had an air flow rate of 2.8 standard m^3/s (6,000 scfm). Exit gas temperature from the ESP's was about 27°C.

Two sources of wastewater were created by the primary air pollution control system-spray cooling water and ESP's. The total volume of water discharged from the primary air pollution control system was 151 ℓ/s (2,400 gpm). For an ESP collecting gas from 30 pots, 4 to 6 ℓ/s (60 to 100 gpm) of cooling water and 9 to 11 ℓ/s (140 to 180 gpm) of water from the ESP were combined and discharged to the wastewater treatment plant.

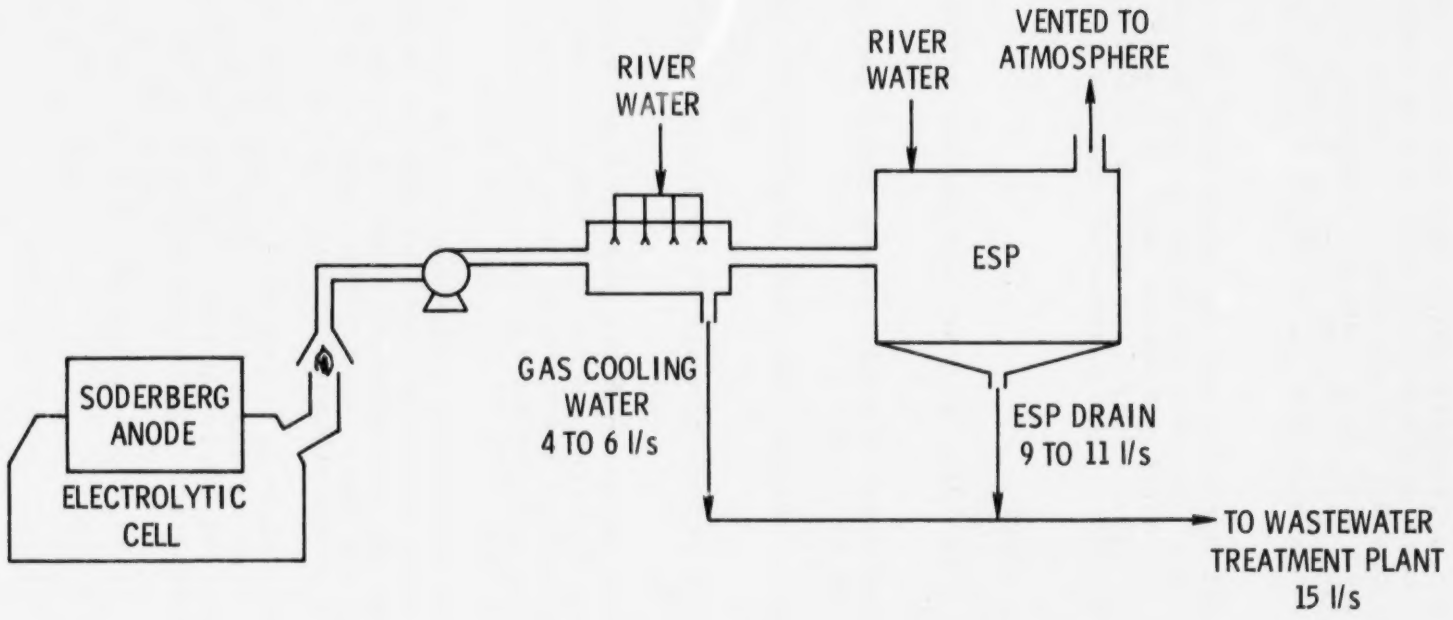

Figure 2. Primary air pollution control system.

The plant was also equipped with a secondary air pollution control system to collect pollutants which escaped into the potroom. Each of the five potrooms was equipped with a room ventilation system and two spray-chamber wet scrubbers. A total of 40 ventilation fans were used with four fans per scrubber unit. Each fan pulled 142 standard m^3/s (300,000 scfm) and each scrubber, therefore, treated 566 standard m^3/s (1,200,000 scfm) of room air.

Each spray-chamber wet scrubber was equipped with four banks of spray nozzels, a screen, one bank of nozzels, and a mist eliminator. Each of the secondary scrubbers used 60 ℓ/s (950 gpm) of once-through river water, totalling 600 ℓ/s (9,500 gpm) of scrubber water discharged to the wastewater treatment plant at pH 6.1.

WASTEWATER TREATMENT PLANT

As described, there were three primary wastewater streams flowing to the treatment plant:

- Combined ESP wash water and gas stream spray cooling water (pH 2.8) at 151 ℓ/s,
- Secondary scrubber system from room ventilation (pH 6.1) at 600 ℓ/s, and
- Briquette cooling water from the paste plant (pH 7) at 13 ℓ/s to 19 ℓ/s.

Storm water runoff was piped into the paste plant wastewater line, but no rainfall occurred during the sampling period. The plant's sanitary wastewater was treated in a separate activated sludge treatment plant and discharged into the main chemical treatment plant at a flow rate of 1.0 ℓ/s (20 gpm).

A flow diagram of the wastewater treatment system is shown in Figure 3. Slacked line, CaO, was added to the ESP wastewater at a rate of 30 g CaO per kilogram of aluminum produced per day in order to remove fluorides. During the sampling period, the plant produced 203.2 metric tons of aluminum per day.

This limed stream then went to a standard clarifier with a hydraulic retention time of about 2 hr. Settled solids, principally calcium fluorides, were pumped to sludge holding ponds. No wastewater was discharged from these ponds.

Clarified water (pH 7) was combined with secondary scrubber water and paste plant cooling water and sent to a settling lagoon with a 20 hr hydraulic retention time. The combined outfall of 771 ℓ/s (16 mgd) was discharged to a river.

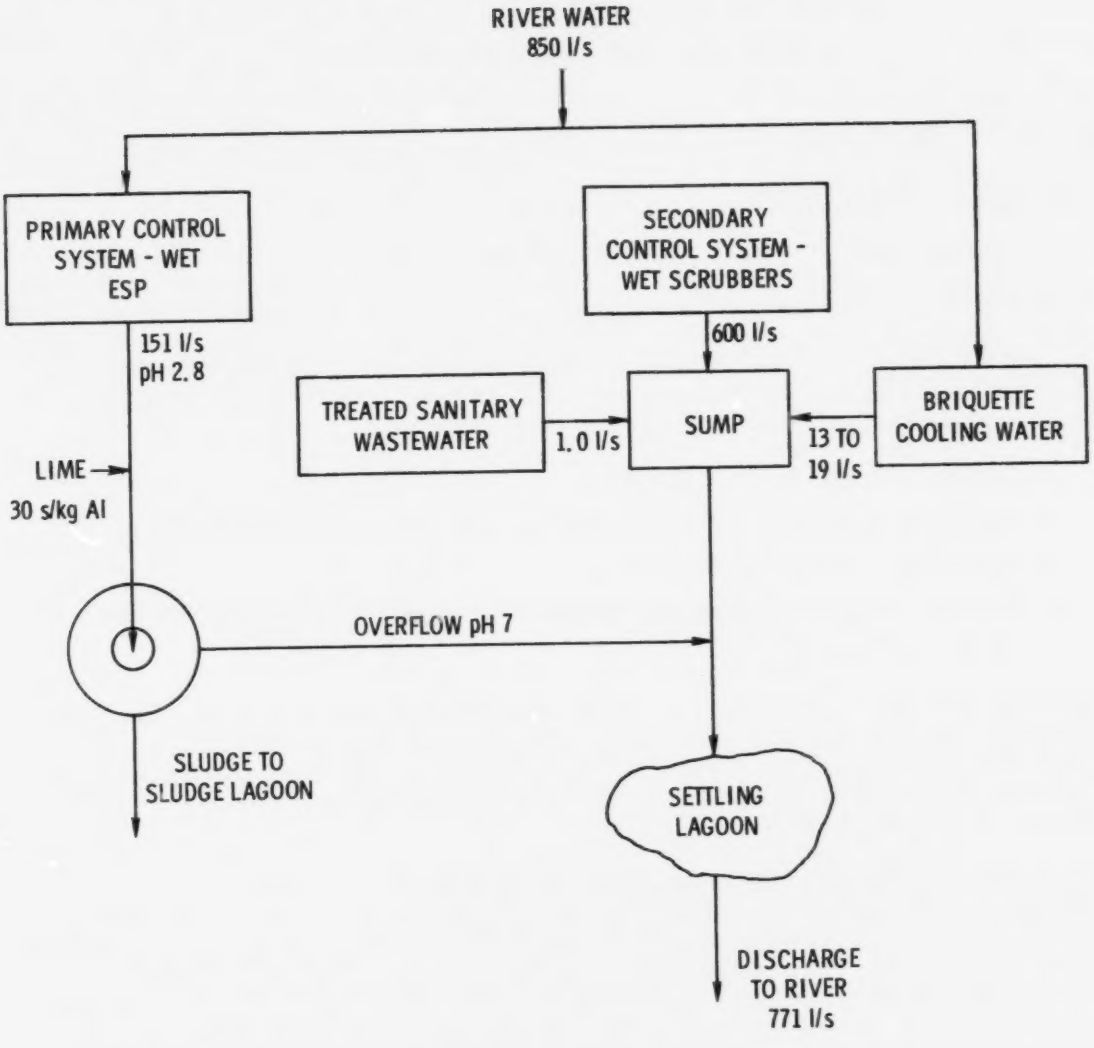

Figure 3. Wastewater treatment plant.

SECTION 4

SAMPLING AND ANALYSIS PROTOCOL

SAMPLING PROCEDURE

Collection Technique

Wastewater sample collection techniques followed those recommended by EPA in Reference 3, with a few modifications designed to better insure sample integrity, chain of custody, and reflect site specific requirements. Since the plant operated 24-hr/day, 7 days/week at full production and since the wastewater stream flow rates varied by less than 10%, 48-hr composited samples were collected at the following locations:

- Plant intake river water,
- Primary control system (ESP's and gas cooling water),
- Secondary control system,
- Paste plant wastewater (anode briquette cooling water),
- Final effluent.

Samples of the treated sanitary wastewater were not collected because of its low flow contribution (1.0 ℓ/s compared to 771 ℓ/s) and because the sanitary treatment plant was oversized and reduced the total organic load to a biochemical oxygen demand (BOD) of less than 5 mg/l.

Because of the way the wastewater treatment system was constructed, it was not possible to use automatic samplers and still guarantee sample integrity. Therefore, 48-hr grab samples were collected once every hour with a 3-gal Teflon®-lined, stainless steel bucket. Aliquots were removed from the bucket using glass beakers and placed in the appropriate sample containers. Care was always taken to insure the sample remained homogenous while in the bucket. It took approximately 5 min to remove all aliquots from the bucket and place them in the containers.

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(3) Draft Final Report: Sampling and Analysis Procedures for Screening of Industrial Effluents for Priority Pollutants. U.S. Environmental Protection Agency, Cincinnati, Ohio, April 1977. 145 pp.

Sampling logistics for subsequent priority pollutant analysis are shown in Table 2 (3, 4). Before sampling began, bottle labels were filled out and affixed to appropriate sample bottles. Figure 4 shows the bottle label designed by MRC for sample identification. Once applied to the bottle, clear tape was put over the label to prevent water damage to the label.

TABLE 2. SAMPLING LOGISTICS FOR PRIORITY POLLUTANTS

Analysis fraction	Container, per sampling point	Preservatives required (3, 4)
Volatile organics	4-40 ml glass vials w/Teflon-lined septa	Keep at 4°C, if residual chlorine is present (KI paper turns blue) then add 0.03 ml of 10% sodium thiosulfate to each bottle.
Nonvolatile organics (base/neutral, acid, pesticide, & PCB's)	1-1 gal amber glass pharmaceutical jug w/Teflon-lined cap	Keep at 4°C
Metals	1-500 ml plastic	In the lab add 5 ml of redistilled HNO_3, keep at 4°C
Cyanide (total)	1-500 ml plastic	Adjust pH ≥ 12 w/10N NaOH, keep at 4°C
Phenol (total)	1-500 ml glass	0.5 g $CuSO_4$ at beginning, adjust pH ≤ 4 w/H_3PO_4 (100 ml con H_3PO_4 to 1 liter of water) keep at 4°C
Asbestos	1-1 liter plastic	1.0 ml of HgCl solution (2.71 g HgCl in 100 ml distilled water), keep at 4°C

Four samples, collected every twelve hours, were collected for volatile organics analysis, as opposed to the one grab sample recommended in Reference 3. Each of the four samples per stream were hermetically sealed immediately after collection and placed in ice at 4°C and were laboratory composited for one analysis per wastewater stream. Since there was no free chlorine,

(4) Manual of Methods for Chemical Analysis of Water and Wastes. EPA-625/6-76-003a (PB 259 973). U.S. Environmental Protection Agency, Cincinnati, Ohio, 1976. 317 pp.

Job _____

Sample or Run No. _____

Sample Location _____

Type of Sample _____

Analyze for _____

Preservation _____

Comments _____

_____

_____

_____

Log No. _____ Date _____

Initials _____

Figure 4. MRC bottle label for sample identification.

tested by potassium iodide (KI) paper, in any of the wastewater streams, preservatives were not required in the volatile organic sample (3).

The grab sampling technique had the added advantage of field compositing samples for total cyanide and total phenol analyses as opposed to the one grab sample method described in Reference 3. Proper preservatives were added to these bottle in the beginning and proper preservation pH maintained throughout the 48-hour sampling period.

Asbestos samples were collected, preserved, and stored at 4°C for possible future analysis.

Sample Container Preparation

All glass containers and beakers were thoroughly cleaned with strong acid (50% sulfuric acid + 50% nitric acid), rinsed in distilled water, and heated in a glass annealing oven at 400°C for at least 30 minutes. Once the bottles cooled to room temperature, Teflon-lined caps were applied.

Plastic bottles were thoroughly cleaned by washing in nitric acid and rinsing several times in distilled water.

During the first grab sampling period, each sample container was seasoned by rinsing with the appropriate wastewater sample and discarding the rinse.

Sample Shipping Procedure

At the completion of the 48-hour sampling period, all containers were checked to insure proper preservation. Then each bottle cap was taped to the bottle to prevent leakage during shipment. All glass bottles were wrapped with plastic glass packing material.

Sample containers were placed in plastic ice chests and filled with ice to maintain sample temperature at 4°C. Each ice chest was taped closed and appropriate shipping labels applied.

Samples were then taken to the airport and shipped via commercial air freight to Dayton for analysis. No sample containers were destroyed during transport to MRC.

ANALYTICAL PROCEDURES

Recommended analytical procedures (3) developed by EPA were used throughout this project. It is important to realize that some of the procedures are still under development and require further verification and validation. Therefore, the data presented serve to identify which of the 129 priority pollutants (Appendix A)

were present and to indicate the general concentration ranges within a factor of two.

Two of the 129 chemical species were not determined in this project: 2,3,7,8-tetrachlorodibenzo-*p*-dioxin (TCDD) and asbestos. EPA-Environmental Monitoring and Support Laboratory (EMSL) recommended that TCDD should be omitted because of its extreme toxicity and potential health hazard involved in preparing standard solutions in the laboratory from the pure compound (3). Asbestos samples were collected, preserved, and stored at 4°C for possible future analysis. Also, due to the source of wastewater in the primary aluminum industry, pesticides were also not analyzed in the samples. The only source of pesticides would be the river intake water.

The analytical procedure (3) divides the 129 priority pollutants into six basic catagories: volatile organics, nonvolatile organics, metals, cyanide, phenol, and asbestos. Appendix B lists the chemical species which belong to each category. The following sections outline the analytical procedures and MRC modifications for analyzing each group of priority pollutants.

Volatile Organics

The recommended method for volatile organic analysis was designed by EPA to determine those chemical species which were amenable to the Bellar purge and trap method (3). Appendix B lists those priority pollutants classified as volatile organics.

Four hermetically sealed 40-ml glass vials collected from each of the five sampling points were composited in the laboratory for one analysis. Two composited solutions were used, one for analysis and one as a backup sample. Figure 5 is a simplified diagram of the analytical scheme for volatile organics analysis.

An internal standard of 1,4-dichlorobutane was added to 5 ml of the composited sample and the sample sparged with helium onto a Tenax GC-silica-packed sample tube. Two tubes were prepared, one for analysis and one duplicate. Tenax tubes were then sealed in glass under a nitrogen atmosphere and stored in a freezer at -18°C until analyzed.

Analyses were carried out using a Hewlett Packard 5981 GC-Mass Spectrometer with 5934 Data System. Sample tubes were heated to 180°C over a 1-minute period and held at that temperature for 4 minutes to desorb the compounds onto a Carbowax 1500 column held at -40°C. For compounds with boiling points below room temperature, cryogenic trapping at -40°C (liquid nitrogen cooling) was found to give better reproducibility of retention time than using the suggested temperature of 30°C. After desorption, the GC column temperature was raised 8°C/minute to 170°C.

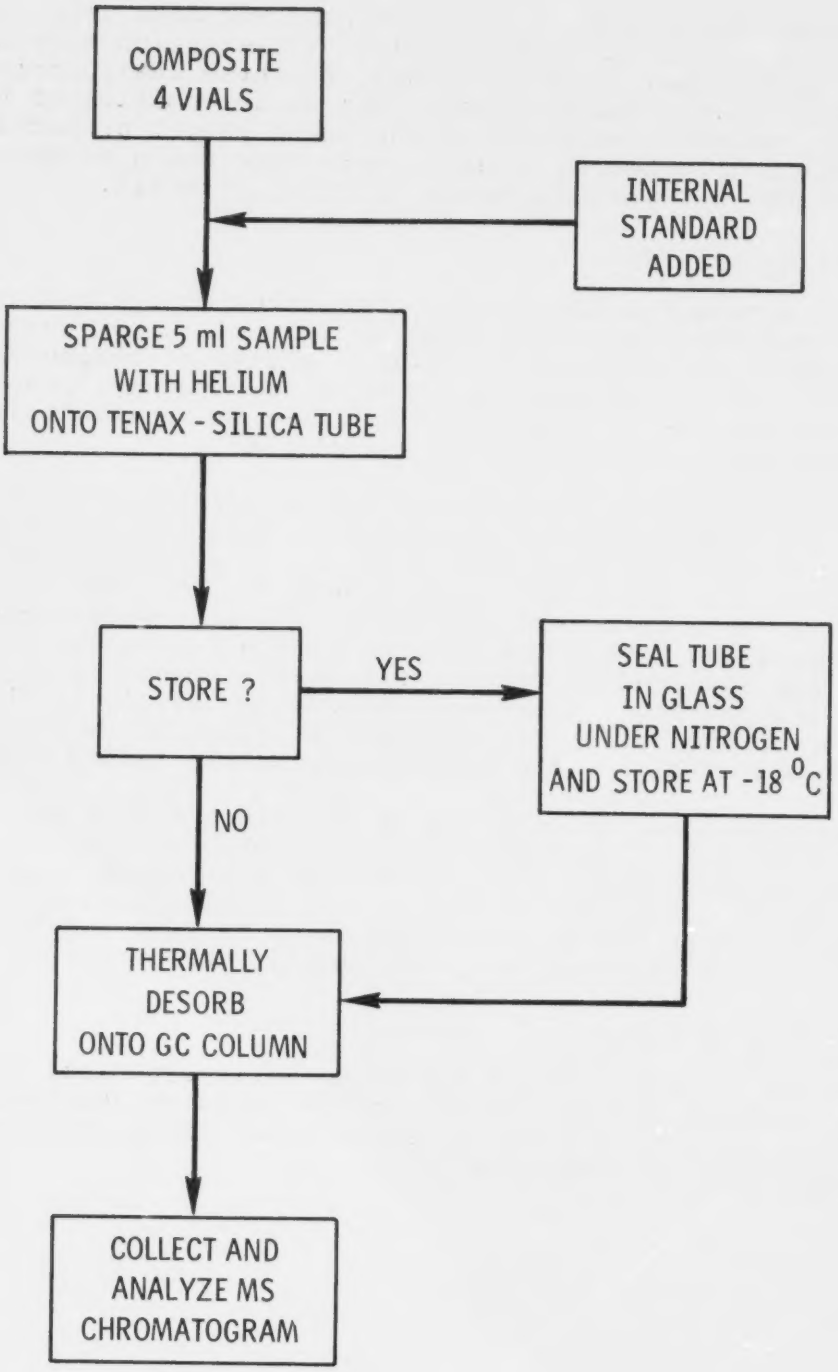

Figure 5. Analytical scheme for volatile organics analysis.

Qualitative identification of a compound was made using three criteria listed in the protocol (3): 1) retention time must coincide with known retention times, 2) three characteristic masses must elute simultaneously, and 3) intensities of the characteristic masses must stand in the known proper proportions. Quantitation of volatile organics were made using response ratios to the 1,4-dichlorobutane internal standard.

Nonvolatile Organics

Nonvolatile organics are divided into three groups for analysis: base/neutral fraction, acid fraction (phenols), and pesticides and polychlorinated biphenyls (PCB). A list of compounds that are classified as nonvolatile organics is given in Appendix B. Due to the sources of wastewater in aluminum manufacturing, pesticides were not analyzed in the samples.

The analytical procedure is described in Reference 3. Figure 6 depicts the sample processing scheme for the base/neutral and acid fractions. The sample solution, 2 ℓ, was made alkaline (pH greater than 11) with sodium hydroxide, and then extracted three times with methylene chloride. The wastewater samples formed emulsions upon extraction with methylene chloride. The problem was resol[illegible]y drawing off small amounts of separated solvent and pouri[illegible]e extract through the sample in the separatory funnel. Separation was also enhanced by slowly dripping the emulsion onto the wall of a slightly tilted flask.

Extracts were dried on a column of anhydrous sodium sulfate, concentrated to 1.0 ml in a Kuderna-Danish (K-D) evaporator with a Snyder column, spiked with deuterated anthracene, sealed in septum capped vials, and stored at 4°C until analyzed. Analyses were performed on the GC-MS system using SP 2250 and Tenax GC columns for base/neutral and acid samples, respectively (3).

Metals

In addition to the volatile and nonvolatile organics, the 129 chemical species include 13 metals, measured as the total metal. All metals were quantified by conventional flame and flameless atomic absorption techniques (4, 5).

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(5) Standard Methods for the Examination of Water and Wastewater, Fourteenth Edition. American Public Health Association, Washington, D.C., 1976. 874 pp.

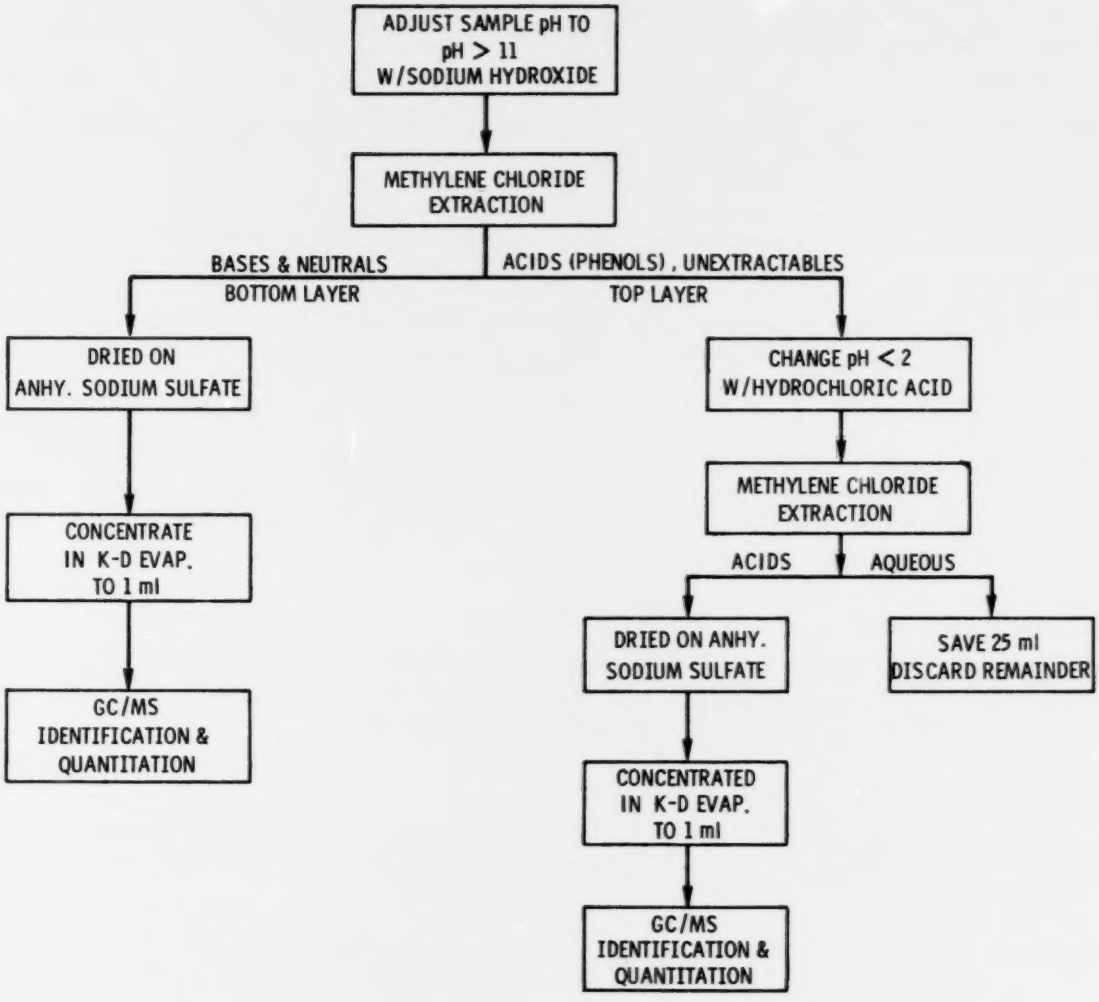

Figure 6. Sample processing scheme for nonvolatile organics analysis.

Five milliters of redistilled nitric acid were added to the metals samples in the laboratory and allowed to sit for two hours before removing aliquots for analysis. Due to the higher solids loading of the wastewater from the primary air pollution collection system, this sample was vacuum filtered with 0.45-μm filters and both the filtrate and filter paper analyzed for metals.

The filter paper sample was parr bombed with nitric acid and the resulting solution diluted to 100 ml with distilled deionized water. Filter paper and reagent blanks were also prepared and analyzed.

The five sampling locations resulted in six samples for metals analysis because one sample required filtration and analysis of filtrate and filter. Three of the samples were split and analyzed as blind repeats. A certified National Bureau of Standards trace elements in water sample and two MRC standards, one in the 10 mg/l concentration range and one in the 0.05 mg/l range were used to calibrate the atomic absorption instrument. Two filter paper blanks, a nitric acid/water, and a distilled water blank were included in the analysis scheme.

Asbestos

Asbestos samples were collected at each of the five sampling points and presented with a HgCl solution (3). Samples were then stored at 4°C for possible future analysis. No asbestos samples were analyzed for this project.

Cyanide (Total)

Total cyanide was analyzed according to the procedure in Reference 3. One blind repeat and one spiked sample were included with the five samples for quality assurance.

Phenol (Total)

In addition to specific phenolic compounds and phenol measured by GC-MS, total phenol was also measured by typical wet chemistry techniques (3-5).

Phenol samples were preserved in the field by adding 1.0 g $CuSO_4$, maintaining the pH to less than 4 with H_3PO_4 and storing the sample at 4°C. Recent research has indicated this preservation technique is adequate for at least 8 days (6). All phenolic samples collected in this study were analyzed within 5 days of collection.

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(6) Carter, M. J. and M. T. Huston. Preservation of Phenolic Compounds in Wastewaters. Environmental Science and Technology, 12(3):309-313, 1978.

SECTION 5

RESULTS AND CONCLUSION

ANALYTICAL RESULTS

Organics

Results of the organic priority pollutant analyses are shown in Table 3. Compounds presented in the table are those found in the base/neutral, acid, and volatile organics fractions. Pesticides were not analyzed due to the nature of the wastewater sources.

Of the list of compounds, the majority of the species were detected in the base/neutral fraction. Only phenol and 2,4-dimethyl phenol were detected in any of the acid fractions. Methylene chloride, toluene, and benzene were the only priority pollutant organics detected in the volatile fractions.

In order to fully understand the quantity of organic species present in each stream and the distribution of the species through the treatment system, the concentration values in Table 3 were multiplied by the appropriate wastewater stream flow rate. This technique shows the difference between simple dilution effects and removal effects, since stream dilution is not an acceptable form of pollution control technology.

Since the plant was producing 203.2 metric tons of aluminum per day, discharge values are also reported as grams of pollutant per metric ton of product produced.

Total Cyanide and Phenol

Samples were also analyzed by conventional wet chemistry techniques to total cyanide and total phenol (4). Results of these analyses are also shown in Table 3. No cyanide was detected in any of the samples below the detection limit of 4 µg/ℓ. The detection limit for total phenol was 5 µg/ℓ.

Metals

The thirteen priority pollutant metals were analyzed by conventional atomic absorption and the results are shown in Table 4.

TABLE 3. ANALYSIS OF ORGANIC PRIORITY POLLUTANTS AND CYANIDE

Stream and flow rate	Priority pollutant observed	Concentration, µg/ℓ	Mass rate, g/day	Discharge factor, g/metric ton Al
Intake river water, 850 ℓ/s	Bis(2-ethyl hexyl)phthalate	20	1,470	7.2
	Anthracene	0.4	30	0.1
	Fluoranthene	1	70	0.3
	Pyrene	1	70	0.3
	Benzo(a)anthracene	2	150	0.7
	Benzo(a)pyrene	2	150	0.7
	Benzo(k)fluoranthene	3	220	1.1
	Methylene chloride	2	150	0.7
	Toluene	2	150	0.7
	Cyanide (total)	<4	<290	<2
	Phenol (total)	<5	<370	<2
Primary control system, 151 ℓ/s	Naphthalene	20	260	1.3
	Acenaphthene	50	650	3.2
	Acenaphthylene	4	50	0.2
	Bis(2-ethyl hexyl)phthalate	5	65	0.3
	Fluorene	50	650	3.2
	Phenanthrene	230	3,000	15
	Anthracene	150	1,960	9.6
	Pyrene	220	2,870	14
	Fluoranthene	320	4,170	21
	Chrysene	230	3,000	15
	Benzo(a)anthracene	180	2,350	12
	Benzo(b)fluoranthene	260	3,390	17
	Benzo(k)fluoranthene	210	2,740	13
	Benzo(a)pyrene	570	7,440	37
	Dibenzo(a,h)anthracene	110	1,430	7.0
	Indeno(1,2,3-cd)pyrene	350	4,570	22
	Benzo(g,h,i)perylene	150	1,960	9.6
	Phenol	70	910	4.5
	Methylene chloride	8	100	0.5
	Toluene	3	40	0.2
	Benzene	6	80	0.4
	Cyanide (total)	<4	<50	<0.3
	Phenol (total)	725	3,600	18
Secondary control system, 600 ℓ/s	Bis(2-ethyl hexyl)phthalate	30	1,560	7.7
	Acenaphthene	0.7	40	0.2
	Anthracene	10	520	2.6
	Fluoranthene	110	5,700	28
	Pyrene	50	2,590	13
	Chrysene	30	1,560	7.7
	Benzo(a)anthracene	40	2,070	10
	Benzo(a)pyrene	40	2,070	10
	Benzo(g,h,i)perylene	8	100	0.5
	Indeno(1,2,3-cd)pyrene	8	100	0.5
	Cyanide (total)	<4	<210	<1
	Phenol (total)	158	8,200	40
Paste plant (briquette cooling), 19 ℓ/s	Bis(2-ethyl hexyl)phthalate	20	30	0.1
	Acenaphthene	2	3	0.01
	Fluorene	2	3	0.01
	Phenanthrene	9	15	0.07
	Anthracene	9	15	0.07
	Fluoranthene	50	80	0.4
	Pyrene	40	70	0.3
	Chrysene	50	80	0.4
	Benzo(a)anthracene	50	80	0.4
	Benzo(k)fluoranthene	70	110	0.5
	Benzo(a)pyrene	60	100	0.5
	Indeno(1,2,3-cd)pyrene	10	20	0.1
	Benzo(g,h,i)perylene	10	20	0.1
	Methylene chloride	8	10	0.05
	Toluene	3	5	0.02
	Cyanide (total)	<4	<7	<0.1
	Phenol (total)	102	170	0.8
Final effluent, 771 ℓ/s	Bis(2-ethyl hexyl)phthalate	10	670	3.3
	Acenaphthylene	7	470	2.3
	Fluorene	1	70	0.3
	Acenaphthene	10	670	3.3
	Anthracene	3	200	1.0
	Fluoranthene	80	5,330	26
	Pyrene	40	2,660	13
	Chrysene	9	600	3.0
	Benzo(a)anthracene	8	530	2.6
	Benzo(a)pyrene	10	670	3.3
	Benzo(g,h,i)perylene	1	70	0.3
	Indeno(1,2,3-cd)pyrene	1	70	0.3
	Benzo(k)fluoranthene	7	470	2.3
	Cyanide (total)	<4	<270	<1
	Phenol (total)	116	7,730	38

TABLE 4. METALS CONCENTRATIONS IN WATER AND WASTEWATER STREAMS ANALYZED BY ATOMIC ABSORPTION METHOD

Metal	Metals concentration by stream, µg/ℓ				
	Intake water	Primary control system	Secondary control system	Paste plant	Final effluent
Antimony	30	450	50	30	40
Arsenic	<10	<10	<10	<10	<10
Beryllium	<10	<10	<10	<10	<10
Cadmium	<5	<20	<10	<10	<10
Chromium	<10	<20	<10	<10	<10
Copper	5.5 ± 0.7	31	21	8.5 ± 0.7	9.0 ± 1.4
Lead	<50	<100	<50	<10	<50
Mercury	<2	<4	<2	<2	<2
Nickel	8.0 ± 1.4	1,130 ± 85	<5	<5	5
Selenium	<1	<2	<1	<1	<1
Silver	<2	<4	<2	<2	<2
Thallium	<50	<90	<1	<1	<1
Zinc	28 ± 2	117	47	34	35 ± 2

Values indicated with the less than sign (<) indicate the metal concentration is below the stated detection limit. Samples were analyzed in duplicate and on two separate days. Fluctuations in concentrations are noted by the plus or minus standard deviation values.

The mass flow rate, given in g/day, of each metal in each of the five streams is given in Table 5. Values were calculated by multiplying the metal concentration (Table 5) by the appropriate stream flow rate value, shown in Figure 3, and converting to g/day.

WASTEWATER TREATMENT PLANT PERFORMANCE

The principal source of organics in the wastewater was from the volatilization of petroleum coke and pitch in the Soderberg anode. These organic vapors were subsequently collected in the air pollution control system and the resulting wastewater discharged to the treatment plant.

Of the metals detected, above instrument detection limits, antimony, copper, nickel, and zinc were discharged at the same rate as the amount coming in with the intake water. There was no gain in metals due to the aluminum plant.

In order to evaluate the removal efficiency of the wastewater treatment plant for priority pollutants, the mass flow rate values were used and are presented in Table 6. Removal efficiencies were calculated by summing the quantity of species in the primary control system stream, secondary control system stream, and paste plant stream and comparing this value to the quantity in the final effluent. Since cyanide, arsenic,

TABLE 5. MASS FLOW RATES AND TREATMENT PLANT REMOVAL EFFICIENCIES FOR METALS

Metal	Metals mass flow rate by stream, g/day					Percent removal[a]
	Intake water	Primary control system	Secondary control system	Paste plant	Final effluent	
Antimony	2,200	5,800	2,600	50	2,700	68
Arsenic	<700	<130	<500	<20	<670	-[b]
Beryllium	<700	<130	<500	<20	<670	-[b]
Cadmium	<360	<260	<500	<20	<670	-[b]
Chromium	<700	<260	<500	<20	<670	-[b]
Copper	400 ± 50	400	1,100	14 ± 1	600 ± 90	60 ± 3
Lead	<3,600	<1,300	<2,600	<20	<3,300	-[b]
Mercury	<150	<50	<100	<3	<130	-[b]
Nickel	590 ± 100	14,700 ± 1,100	<260	<8	330	98 ± 2
Selenium	<70	<30	<50	<2	<70	-[b]
Silver	<150	<50	<100	<3	<130	-[b]
Thallium	<3,600	<1,200	<50	<2	<70	-[b]
Zinc	2,100 ± 150	1,500	2,400	60	2,300 ± 130	42 ± 2

[a]Value calculated by subtracting the sum of columns 2 through 4 from the value in column 5 and dividing the difference by the sum of columns 2 through 4 and converting into percent.

[b]Since all concentrations were below instrument detection limits, percent removal values were not calculated.

TABLE 6. TREATMENT PLANT REMOVAL EFFICIENCIES FOR PRIORITY POLLUTANTS

Primary pollutant	Mass flow rate in stream, g/day					Percent removal[a]
	Intake water	Primary control system	Secondary control system	Paste plant discharge	Final effluent	
Bis(2-ethyl hexyl) phthalate	1,470	65	1,560	30	670	32
Naphthalene	-[b]	260	-	-	-	100
Acenaphthene	-	650	40	3	670	3
Acenaphthylene	-	50	-	-	470	-[c]
Fluorene	-	650	-	3	70	89
Phenanthrene	-	230	-	15	-	100
Anthracene	30	1,960	520	15	200	91
Pyrene	70	2,870	2,590	70	2,660	52
Fluoranthene	70	4,170	5,700	80	5,330	46
Chrysene	-	3,000	1,560	80	600	87
Benzo(a)anthracene	150	2,350	2,070	80	530	88
Benzo(b)fluoranthene	-	3,390	-	-	-	100
Benzo(k)Fluoranthene	220	2,740	-	110	470	84
Benzo(a)pyrene	150	7,440	2,070	100	670	93
Dibenzo(a,h)anthracene	-	1,430	-	-	-	100
Indeno(1,2,3-cd)pyrene	-	4,570	100	20	70	99
Benzo(1,2,3-cd)perylene	-	1,960	100	20	70	97
Phenol	-	910	-	-	-	100
Methylene chloride	150	100	-	10	-	100
Toluene	150	40	-	5	-	100
Benzene	-	80	-	-	-	100
Phenol (total)	290	3,590	8,190	170	7,730	37
Antimony (total)	2,200	5,800	2,600	50	2,700	68
Copper (total)	400 ± 50	400	1,100	14 ± 1	600 ± 90	60 ± 3
Nickel (total)	590 ± 100	14,700 ± 1,100	<260	<8	330	98 ± 2
Zinc (total)	2,100 ± 150	1,500	2,400	60	2,300 ± 130	42 ± 2

[a]Value calculated by subtracting the sum of columns 2 through 4 from the value in column 5 and dividing the difference by the sum of columns 2 through 4 and converting into percent.

[b]Blanks indicate species not present in stream sample.

[c]Nondeterminable--value in effluent greater than sum of input values.

beryllium, cadmium, chromium, lead, mercury, selenium, silver, and thallium were not detected in any stream, efficiency values could not be determined.

Based on the values in Table 6, removal efficiencies of greater than 85% were achieved for most organic species detected. Organic chemical species with lower removal efficiency values are bis(2-ethyl hexyl) phthalate, acenaphthene, pyrene, fluoranthene, and total phenol.

The treatment plant is moderately effective at removing antimony, copper and zinc, and very effective at removing nickel.

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APPENDIX A

RECOMMENDED LIST OF PRIORITY POLLUTANTS

TABLE A-1. RECOMMENDED LIST OF PRIORITY POLLUTANTS

Compound name
Acenaphthene
Acrolein
Acrylonitrile
Benzene
Benzidine
Carbon tetrachloride (tetrachloromethane)
Chlorinated benzenes (other than dichlorobenzenes)
Chlorobenzene
1,2,4-Trichlorobenzene
Hexachlorobenzene
Chlorinated ethanes (including 1,2-dichloroethane, 1,1,1-trichloroethane and hexachloroethane)
1,2-Dichloroethane
1,1,1-Trichloroethane
Hexachloroethane
1,1-Dichloroethane
1,1,2-Trichloroethane
1,1,2,2-Tetrachloroethane
Chloroethane
Chloroalkyl ethers (chloromethyl, chloroethyl and mixed ethers)
Bis(chloromethyl) ether
Bis(2-chloroethyl) ether
2-Chloroethyl vinyl ether (mixed)
Chlorinated naphthalene
2-Chloronaphthalene

(continued)

TABLE A-1 (continued).

Compound name
Chlorinated phenols (other than those listed elsewhere; includes trichlorophenols and chlorinated cresols)
2,4,6-Trichlorophenol
p-Chloro-*m*-cresol (4-chloro-3-methylphenol)
Chloroform (trichloromethane)
2-Chlorophenol
Dichlorobenzenes
1,2-Dichlorobenzene
1,3-Dichlorobenzene
1,4-Dichlorobenzene
Dichlorobenzidine
3,3'-Dichlorobenzidine
Dichloroethylenes (1,1-dichloroethylene and 1,2-dichloroethylene)
1,1-Dichloroethylene (vinylidine chloride)
1,2-*Trans*-dichloroethylene
2,4-Dichlorophenol
Dichloropropane and dichloropropene
1,2-Dichloropropane
1,3-Dichloropropylene (*cis* and *trans*-1,3-dichloropropene)
2,4-Dimethylphenol
Dinitrotoluene
2,4-Dinitrotoluene
2,6-Dinitrotoluene
1,2-Diphenylhydrazine
Ethylbenzene
Fluoranthene

(continued)

TABLE A-1 (continued).

Compound name
Haloethers (other than those listed elsewhere)
4-Chlorophenyl phenyl ether
4-Bromophenyl phenyl ether
Bis(2-chloroisopropyl) ether
Bis(2-chloroethoxy) methane
Halomethanes (other than those listed elsewhere)
Methylene chloride (dichloromethane)
Methyl chloride (chloromethane)
Methyl bromide (bromomethane)
Bromoform (tribromomethane)
Dichlorobromomethane
Trichlorofluoromethane
Dichlorodifluoromethane
Chlorodibromomethane
Hexachlorobutadiene
Hexachlorocyclopentadiene
Isophorone (3,5,5-trimethyl-2-cyclohexen-1-one)
Naphthalene
Nitrobenzene
Nitrophenols (including 2,4-dinitrophenol and dinitrocresol)
2-Nitrophenol
4-Nitrophenol
2,4-Dinitrophenol
4,6-Dinitro-*o*-cresol
Nitrosoamines
N-nitrosodimethylamine
N-nitrosodiphenylamine
N-nitroso-di-n-propylamine
Penta chlorophenol
Phenol

(continued)

TABLE A-1 (continued).

Compound name
Phthalate esters
Bis(2-ethylhexyl) phthalate
Butyl benzyl phthalate
Di-n-butyl phthalate
Diethyl phthalate
Dimethyl phthalate
Di-n-octyl phthalate
Polynuclear aromatic hydrocarbons
Benz(a)anthracene (1,2-benzanthracene)
Benzo(a)pyrene (3,4-benzopyrene)
3,4-Benzofluoranthene
Benzo(k)fluoranthene (11,12-benzofluoranthene)
Chrysene
Acenaphthylene
Anthracene
Benzo(ghi)perylene (1,12-benzoperylene)
Fluorene
Phenanthrene
Dibenz(ah)anthracene (1,2,5,6-dibenzanthracene)
Indeno(1,2,3-cd)pyrene (2,3-*o*-phenylenepyrene)
Pyrene
Tetrachloroethylene
Toluene
Trichloroethylene
Vinyl chloride (chloroethylene)
Pesticides and metabolites
Aldrin
Dieldrin
Chlorodane (technical mixture and metabolites)
DDT and metabolites
4,4'-DDT
4,4'-DDE (p,p'-DDX)
4,4'-DDD (p,p'-TDE)

(continued)

TABLE A-1 (continued).

Compound name
Endosulfan and metabolites
α-Endosulfan
β-Endosulfan
Endosulfan sulfate
Endrin and metabolites
Endrin
Endrin aldehyde
Heptachlor and metabolites
Heptachlor
Heptachlor epoxide
Hexachlorocyclohexane
α-BHC
β-BHC
λ-BHC (lindane)
δ-BHC
Polychlorinated biphenyls (PCB)
PCB-1242 (Arochlor 1242)
PCB-1254 (Arochlor 1254)
PCB-1221 (Arochlor 1221)
PCB-1232 (Arochlor 1232)
PCB-1248 (Arochlor 1248)
PCB-1260 (Arochlor 1260)
PCB-1016 (Arochlor 1016)
Toxaphene
Elements
Antimony (Total)
Arsenic (Total)
Asbestos (Fibrous)
Beryllium (Total)
Cadmium (Total)
Chromium (Total)
Copper (Total)
Cyanide (Total)
Lead (Total)

(continued)

TABLE A-1 (continued).

Compound name
Elements (continued)
Mercury (Total)
Nickel (Total)
Selenium (Total)
Silver (Total)
Thallium (Total)
Zinc (Total)
2,3,7,8-Tetrachlorodibenzo-*p*-dioxin (TCDD)

APPENDIX B

PRIORITY POLLUTANT ANALYSIS FRACTIONS

TABLE B-1. VOLATILE COMPOUNDS

Compound	Compound
Chloromethane	1,2-Dichloropropane
Dichlorodifluoromethane	*trans*-1,3-dichloropropene
Bromomethane	Trichloroethylene
Vinyl chloride	Dibromochloromethane
Chloroethane	*Cis*-1,3-dichloropropene
Methylene chloride	1,1,2-Trichloroethane
Trichlorofluoromethane	Benzene
1,1,-Dichloroethylene	2-Chloroethyl vinyl ether
1,1-Dichloroethane	Bromoform
trans-1,2,-dichloroethane	1,1,2,2-Tetrachloroethylene
Chloroform	1,1,2,2-Tetrachloroethane
1,2-Dichloroethane	Toluene
1,1,1-Trichloroethane	Chlorobenzene
Carbon tetrachloride	Ethylbenzene
Bromodichloromethane	Acrolein
Bis(chloromethyl) ether	Acrylonitrile

TABLE B-2. BASE NEUTRAL EXTRACTABLE COMPOUNDS

Compound	Compound
1,3-Dichlorobenzene	Anthracene
1,4-Dichlorobenzene	Diethyl phthalate
Hexachloroethane	Dimethyl phthalate
1,2-Dichlorobenzene	Fluoranthene
Bis(2-chloroisopropyl) ether	Pyrene
Hexachlorobutadiene	Di-n-butyl phthalate
1,2,4-Trichlorobenzene	Benzidine
Naphthalene	Butyl benzyl phthalate
Bis(2-chloroethyl) ether	Chrysene
Hexachlorocyclopentadiene	Bis(2-ethylhexyl) phthalate
Nitrobenzene	Benz(a)anthracene
Bis(2-chloroethoxy) methane	Benzo(b)fluoranthene
2-Chloronaphthalene	Benzo(k)fluoranthene
Acenaphthylene	Benzo(a)pyrene
Acenaphthene	Indeno(1,2,3-cd)pyrene
Isophorone	Dibenz(a,h)anthracene
Fluorene	Benzo(g,h,i)perylene
2,6-Dinitrotoluene	N-nitrosodimethylamine
1,2-Diphenylhydrazine	N-nitroso-di-n-propylamine
2,4-Dinitrotoluene	4-Chlorophenyl phenyl ether
N-nitrosodiphenylamine	3,3'-Dichlorobenzidine
Hexachlorobenzene	2,3,7,8-Tetrachlorodibenzo-*p*-dioxin[a]
4-Bromophenyl phenyl ether	Bis-(chloromethyl) ether
Phenanthrene	

[a]This compound was specifically listed in the consent decree. Because of TCDD's extreme toxicity, EPA recommends that laboratories not acquire analytical standards for this compound.

TABLE B-3. ACID EXTRACTABLE COMPOUNDS

2-Chlorophenol
Phenol
2,4-Dichlorophenol
2-Nitrophenol
p-Chloro-*m*-cresol
2,4,6-Trichlorophenol
2,4-Dimethylphenol
2,4-Dinitrophenol
4,6-Dinitro-*o*-cresol
4-Nitrophenol
Pentachlorophenol

TABLE B-4. PESTICIDES AND PCB

Compound
β-Endosulfan
α-BHC
γ-BHC
β-BHC
Aldrin
Heptachlor
Heptachlor epoxide
α-Endosulfan
Dieldrin
4,4'-DDE
4,4'-DDD
4,4'-DDT
Endrin
Endosulfan sulfate
δ-BHC
Chlordane
Toxaphene
PCB-1242 (Aroclor 1242)
PCB-1254 (Aroclor 1254)
PCB-1221 (Aroclor 1221)
PCB-1232 (Aroclor 1232)
PCB-1248 (Aroclor 1248)
PCB-1260 (Aroclor 1260)
PCB-1016 (Aroclor 1016)

TABLE B-5. METALS AND OTHER COMPOUNDS

Metals, total	Others
Antimony	Asbestos
Arsenic	Cyanide
Beryllium	
Cadmium	
Chromium	
Copper	
Lead	
Mercury	
Nickel	
Selenium	
Silver	
Thallium	
Zinc	

CONVERSION FACTORS AND METRIC PREFIXES (7)

CONVERSION FACTORS

To convert from	To	Multiply by
Degree Celsius (°C)	Degree Fahrenheit (°F)	$t_{°F} = 1.8\ t_{°C} + 32$
Kilogram (kg)	Pound-mass (avoirdupois)	2.205
Liter/s (ℓ/s)	Gallon (U.S. liquid)/min (gpm)	1.585×10^{1}
Meters^3/s (m^3/s)	Foot^3/min (cfm)	2.119×10^{3}

METRIC PREFIXES

Prefix	Symbol	Multiplication factor	Example
Kilo	k	10^{3}	5 kg = 5×10^{3} grams
Milli	m	10^{-3}	5 mg = 5×10^{-3} gram
Micro	μ	10^{-6}	5 mg = 5×10^{-3} gram

(7) Standard for Metric Practice. ANSI/ASTM Designation: E 380-76$^{\varepsilon}$, IEEE Std 268-1976, American Society for Testing and Materials, Philadelphia, Pennsylvania, February 1976. 37 p.